MR Aug. 1939

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

August 1939 as
Memorandum Report

HEAT-TRANSFER TESTS OF A STEEL CYLINDER BARREL

WITH ALUMINUM FINS

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NACA

WASHINGTON

E-194

MEMORANDUM REPORT

for

Bureau of Aeronautics, Navy Department

HEAT-TRANSFER TESTS OF A STEEL CYLINDER BARREL WITH ALUMINUM FINS

By Herman H. Ellerbrock, Jr.

INTRODUCTION

Tests conducted by this laboratory on finned cylinders have shown that, for a given weight of material, the finning on the heads of modern cylinders can be greatly improved by using preformed fins, but that for the barrel no great improvement can be made (reference 1). By a modern cylinder is meant one with an aluminum head with aluminum fins cast integrally and a steel barrel with steel fins. An improvement can be made in the barrel fins by adding fin weight, which means, in general, fin width (references 1 and 2). Trouble is encountered in radial engine installations when adding width to the barrel fins because of the small distance between adjacent cylinder barrels and also wide, thin fins are not strong. A possible solution of the barrel-cooling problem is to use preformed aluminum or copper fins on a steel barrel. Use of aluminum or copper fins instead of steel fins should greatly improve the heat transfer of the barrel if a reasonably satisfactory bond is obtained (references 1 and 2).

At the request of the Bureau of Aeronautics, Navy Department a steel cylinder barrel with aluminum fins has been tested and the results presented herein. The object of the tests was to determine the heat-transfer coefficients of the cylinder and the excellence of the bond between the steel barrel and the aluminum fins. Comparison is made of the results with those of steel cylinders with steel fins and aluminum cylinders with aluminum fins.

APPARATUS

Test Cylinder

The cylinder, see figure 1, was made of preformed aluminum fins imbedded in an aluminum base, which in turn was bonded to a $3\frac{1}{2}$-inch steel barrel. The method of construction provided aluminum spacers between the fins as shown in figure 2. The space between fins was 0.045 inch, the thickness of the fins 0.031 inch, and the width 1.28

inches. The cylinder was electrically heated with a wire coil wound on a soapstone core, which was inserted in the cylinder. Loss of heat from the ends of the cylinder was eliminated by using cylindrical guard rings made of sheet metal on each end of the cylinder, as shown in figure 3. Each guard ring was filled with rock wool. Surface temperatures were obtained at 29 points, as shown in figure 2, by means of iron constantan thermocouples made from No. 40 gage wire. Nine of the thermocouples measured the temperature of the steel barrel every $22\frac{1}{2}^{\circ}$ from front to rear of the cylinder, and five measured the temperature of the aluminum spacers every 45°. Thermocouples were placed on a number of fins so as not to block the air flow in any one fin space. The thermocouples were shellacked to the fins and brought out through a copper tube to a cold junction board, as shown in figure 1. An ammeter and voltmeter were used to measure the electrical input to the cylinder and a potentiometer measured the cylinder temperature.

Jacket

The cylinder was enclosed in a wood jacket, as shown in figure 3, and air was drawn over the setup with a Roots blower. The jacket shape and apparatus used for such a test are fully described in references 3 and 4. The diameter of the guard rings was the same as the outside diameter of the fin tips, and thus the guard rings fitted tight against the jacket. The weight of air passing through the jacket was measured with thin-plate orifices placed in the ends of a large tank. Temperatures of the air at the orifices and of the cold junction were obtained with alcohol thermometers.

METHODS

Tests

The tests were conducted by varying the speed of the blower, thus varying the velocity of the air over the fins. The weight velocity of the cooling air over the fins varied from approximately 1 to 9.5 pounds per second per square foot of free area between the fins. All tests were conducted with an approximately constant heat input to the cylinder of 83 Btu per square inch of wall area per hour. The recorded data were the electrical power input to the test cylinder, the temperature of the air entering the orifice tank, the pressure drop across the orifice tank, the cold junction temperature, and the temperatures at the various points on the cooling surface.

Computations

The weight velocity of the cooling air $V\rho_1 g$ over the fins was calculated by dividing the weight of air passing through the jacket by the free-flow area between the fins.

The method of calculating the weight of air passing through the jacket is given in reference 5.

The experimental average surface heat-transfer coefficient q was obtained by dividing the heat input per hour by the product of the area of the total cooling surface and the difference between the average temperature of the cooling surface and the entering-air temperature. The average temperature of the cooling surface was based on the temperatures of the fins and the aluminum spacers.

The experimental average over-all heat-transfer coefficient U was obtained by dividing the heat input per hour by the product of the area of the wall surface of the cylinder and the difference between the average temperature of the wall surface and the entering-air temperature.

Calculated average over-all heat-transfer coefficient U was obtained from the equation

$$U = \frac{q}{s + t}\left[\frac{2}{a}\left(1 + \frac{w}{2R_b}\right)\tanh aw' + s\right] \qquad (1)$$

as derived in reference 6, where

$$a = \sqrt{\frac{2q}{k_m t}}$$

q surface heat-transfer coefficient, Btu per square inch per °F per hour

s average space between fins, inches

t average fin thickness, inches

w fin width, inches

w' $w + t/2$, effective fin width, inches

R_b radius from center of cylinder to fin root, inches

k_m thermal conductivity of metal, Btu per square inch per °F through 1 inch per hour (2.17 for steel; 9.92 for pure aluminum)

This equation has been experimentally verified for fins of steel, copper, and aluminum alloy. (See references 1, 2, 3, 6, and 7.)

RESULTS AND DISCUSSION

Heat-Transfer Tests

The surface heat-transfer coefficient q of finned cylinders can be correlated for an air-flow arrangement as used in the present tests in terms of functions defining a single curve and involving the fin dimensions, the cylinder diameter, and the air-stream characteristics (reference 7). Thus it has been found for cylinders enclosed in a jacket and cooled by a blower,

$$\frac{qs}{k_a} = f\left(\frac{V\rho_1 gs^2}{12\mu D^{0.25}}\right) \tag{2}$$

where

k_a thermal conductivity of the cooling air

μ absolute viscosity of the cooling air

D diameter of cylinder at fin root $(2R_b)$

Figure 9(d) of reference 7 shows a curve, established from tests on a large number of cylinders with an air-flow arrangement as in the present tests, plotted in terms of functions of the foregoing equation. Surface heat-transfer coefficients for a cylinder with fin and cylinder dimensions the same as for the test cylinder were calculated from this curve for several weight velocities between the fins. The results are shown in the curve marked "calculated coefficients" in figure 4. The experimental surface heat-transfer coefficients for the test cylinder are also shown plotted in figure 4. Good agreement exists between the experimental and calculated coefficients which would be expected.

From the calculated surface heat-transfer coefficients of figure 4, over-all heat-transfer coefficients were calculated according to equation (1) for a steel cylinder with steel fins and for an aluminum cylinder with aluminum fins cast integrally. The dimensions of the fins on both of the foregoing cylinders were the same as for the test cylinder, and the aluminum cylinder was assumed to have a conductivity of 9.92 Btu per square inch per °F per hour through 1 inch. The results are plotted in figure 5. Plotted on figure 5 are also the experimental over-all coefficients of the test cylinder based on both the temperature difference between the aluminum spacers and the cooling air and the temperature difference between the steel barrel and the cooling air.

The experimental coefficients based on the former temperature difference agree very well with the calculated coefficients for the aluminum cylinder with aluminum fins cast integrally showing that the material of the fins in the test cylinder must be pure aluminum, and that the fin bond is exceptionally good. The experimental coefficients based on the temperature difference between the steel barrel and the cooling air fall about 18 percent on an average below the experimental coefficients based on the difference between the temperatures of the spacers and the cooling air, showing that there is a drop in temperature in the bond between the steel and the aluminum. The experimental coefficients based on the steel barrel temperatures, however, are about 30 percent better on an average than the calculated coefficients for a steel cylinder with steel fins, showing that an appreciable gain may be obtained by using aluminum fins instead of steel fins, although the bond is not perfect.

Figure 6 shows the temperature differences between the aluminum spacers and the cooling air and the temperature differences between the steel barrel and the cooling air plotted against weight velocity for various positions around the cylinder. The difference between the two curves at any one position is the temperature drop through the bond. The drop is appreciable in some positions and in one position (135° from front of cylinder) the temperatures of the steel barrel and the aluminum spacer were identical. This curve shows that further improvement of the bond is needed, but that it is possible to obtain a bond where negligible temperature drop occurs.

Physical Tests

At the conclusion of the heat-transfer tests the cylinder was cut in half and one half was cut in quarters in order to determine how good the bond between the steel and aluminum was mechanically. One edge of one of the quarters was polished and etched, and the result is shown in figure 7. The outline of the fins in the aluminum base and a line between the aluminum and steel can be clearly seen. The other quarter of the test cylinder was heated 10 times to 450° F and quenched in water at room temperature. After these tests, the outline of the fins in the aluminum base was more prominent. The steel was then pried loose from the aluminum in the quarter that had been heat-treated, and considerable force was required to separate the two parts. About one-third of the contacting surface appeared to have a much better bond than the other two-thirds. The bond from a mechanical standpoint, however, is considered to be very good.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 7, 1939.

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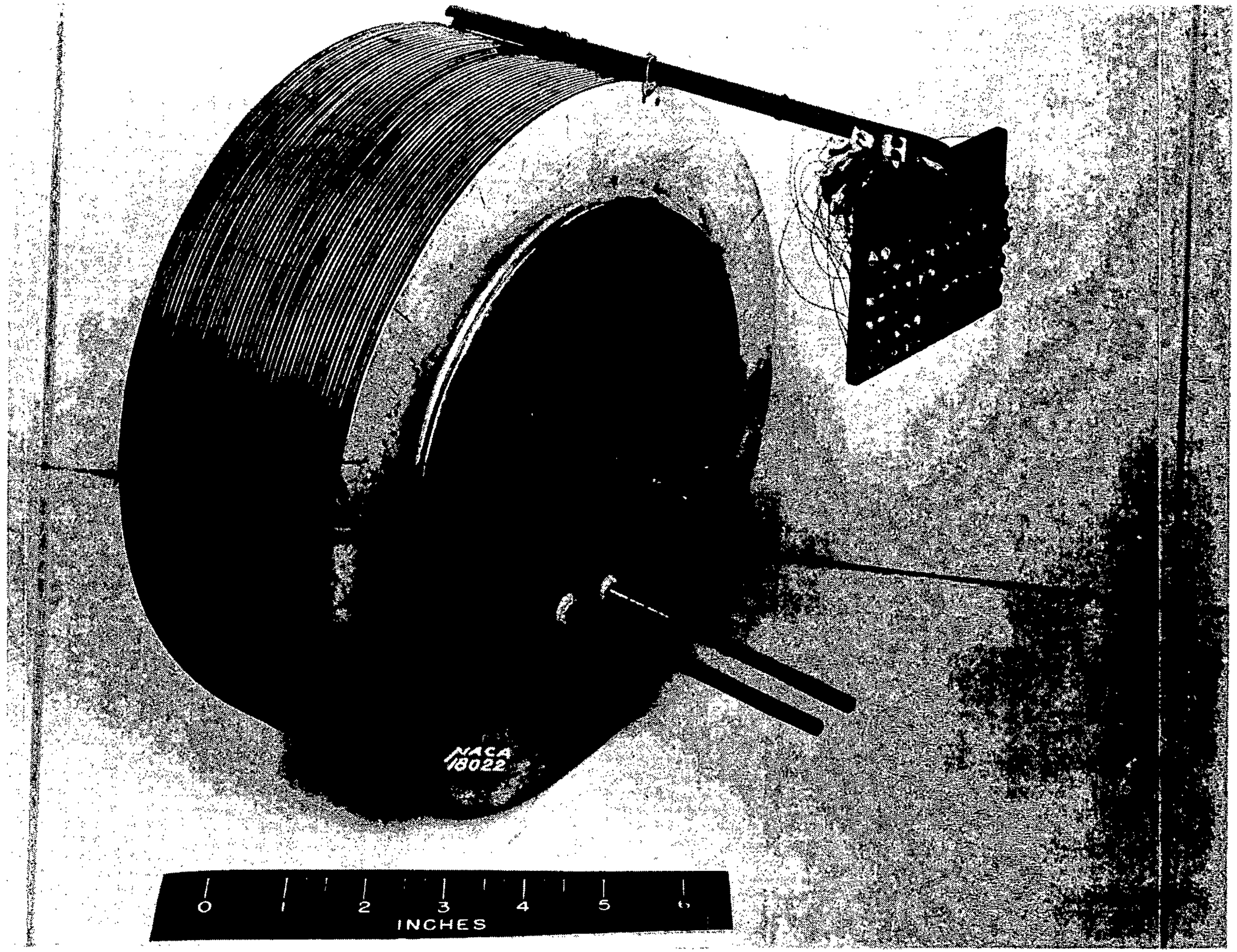

Figure 1. - Test cylinder with cold junction board attached and heating core inserted.

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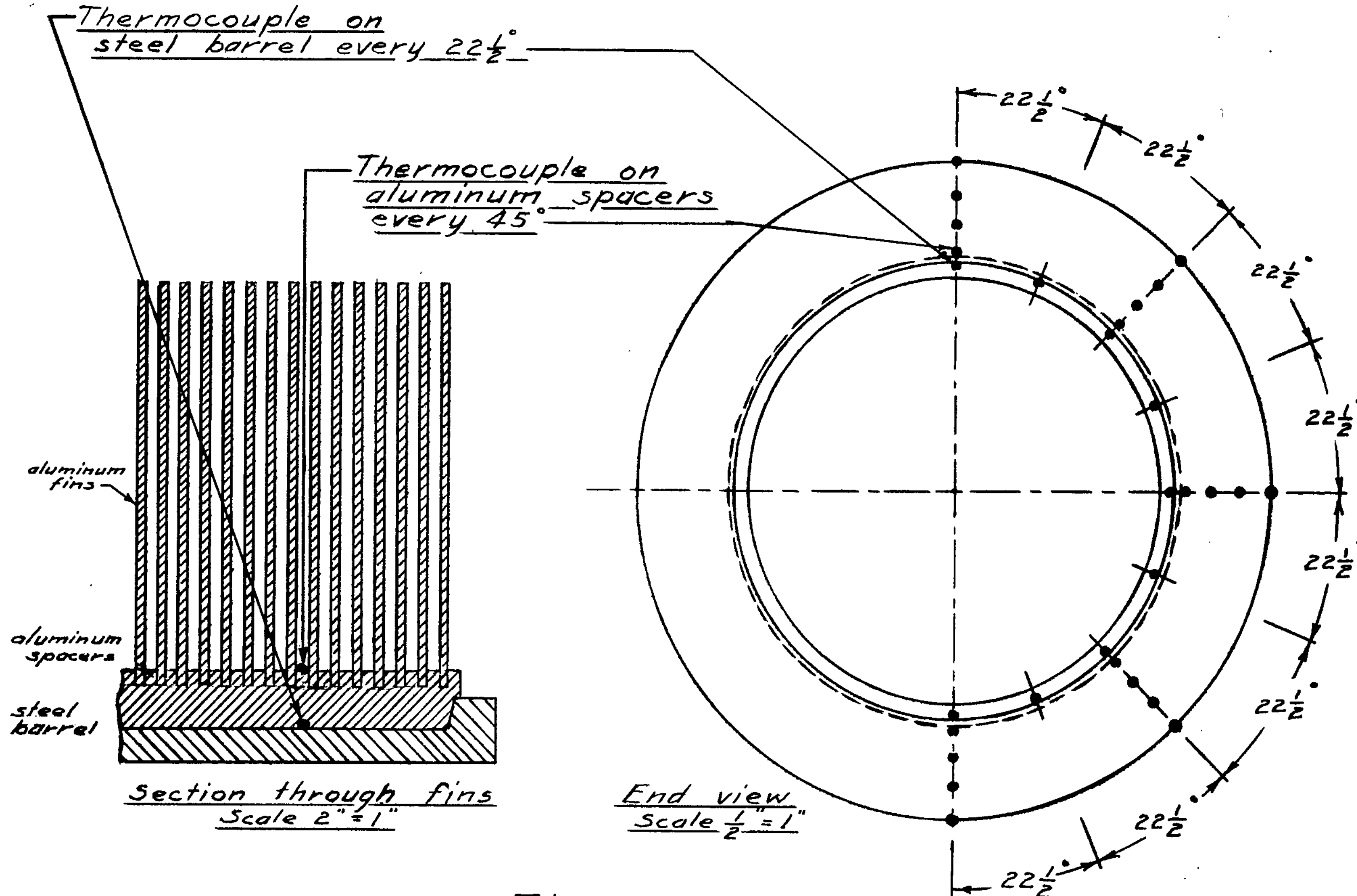

Figure 2.-
Location of thermocouples on test cylinder

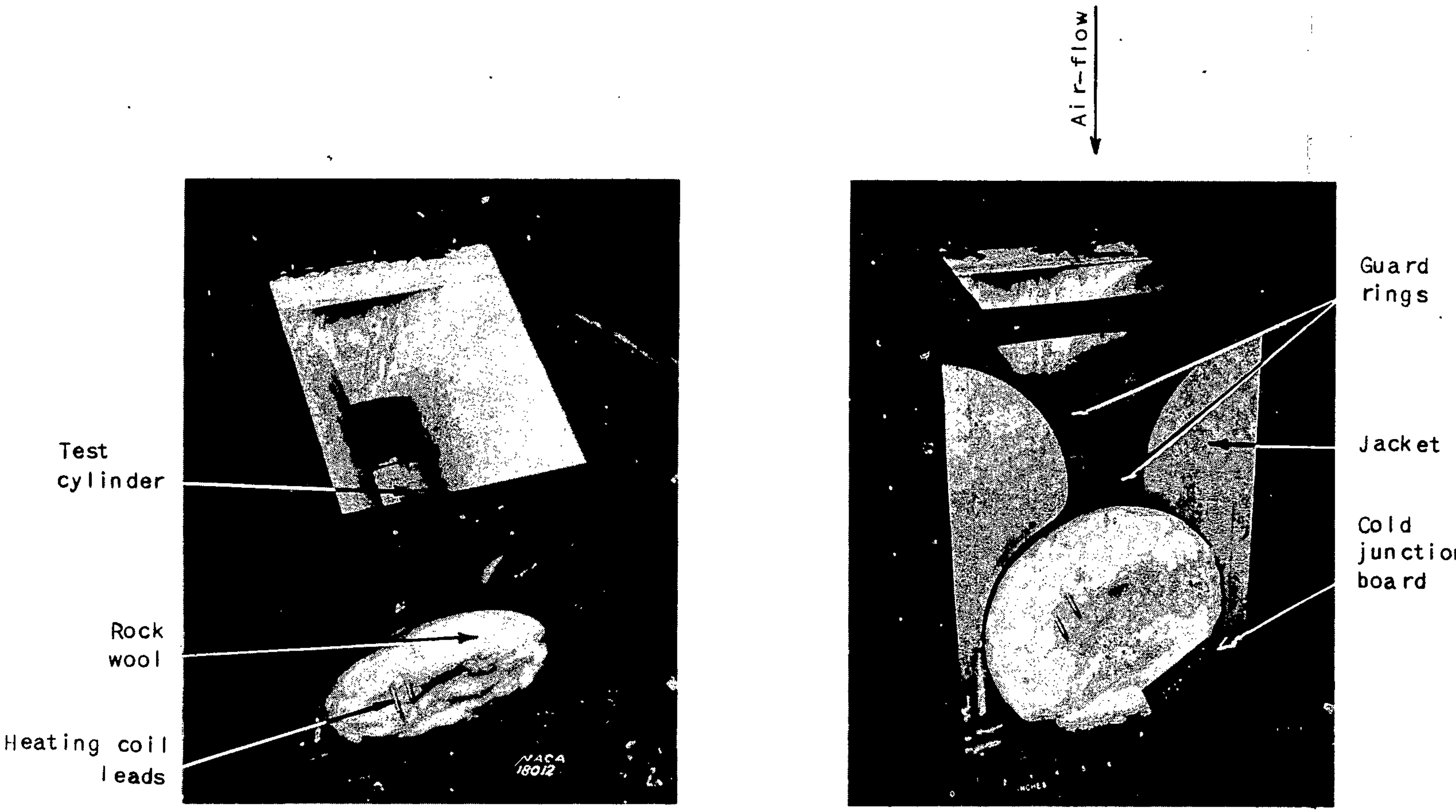

Figure 3. - Test-cylinder setup showing jacket and guard rings.

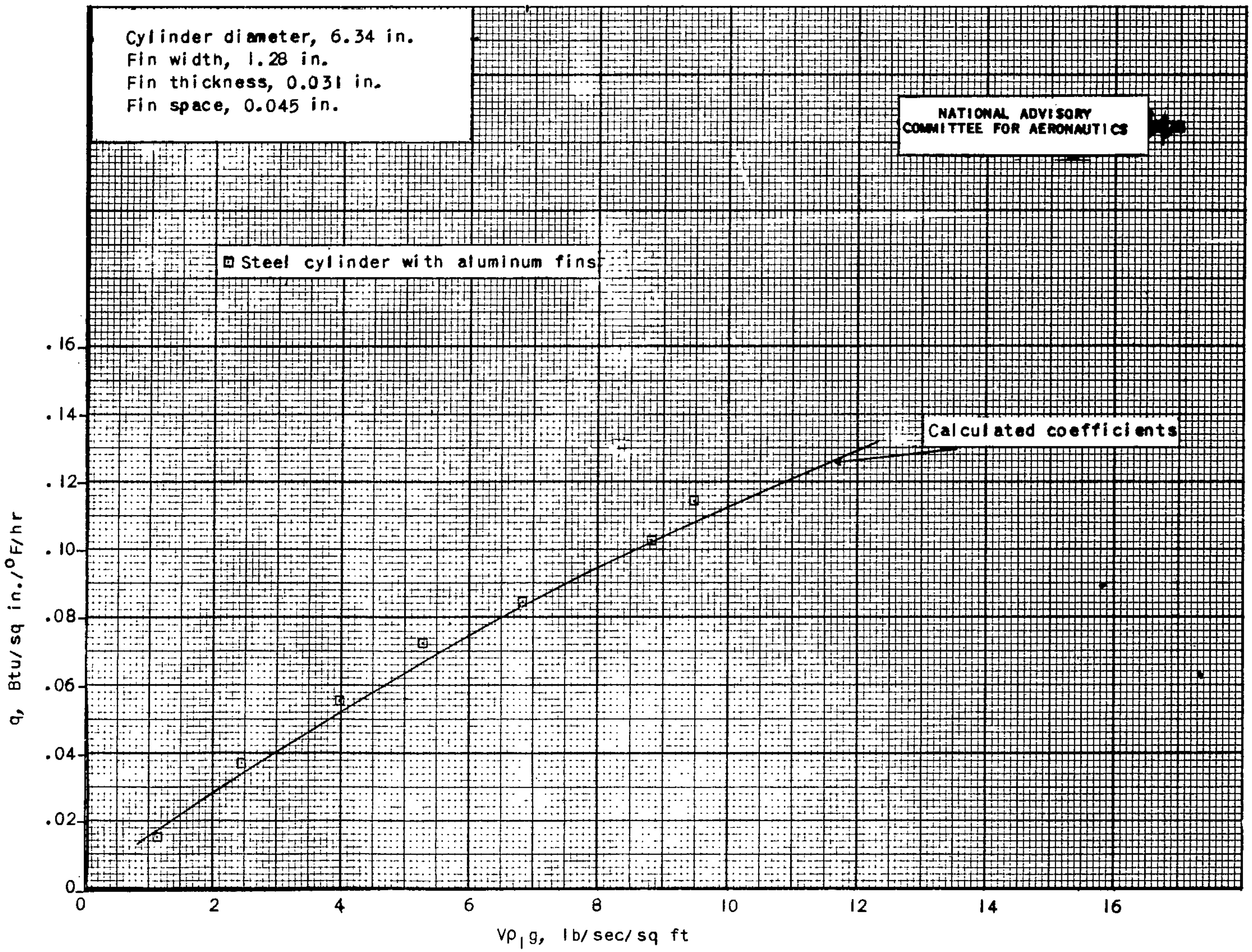

Figure 4. - Comparison of surface heat-transfer coefficients of test cylinder with calculated coefficients.

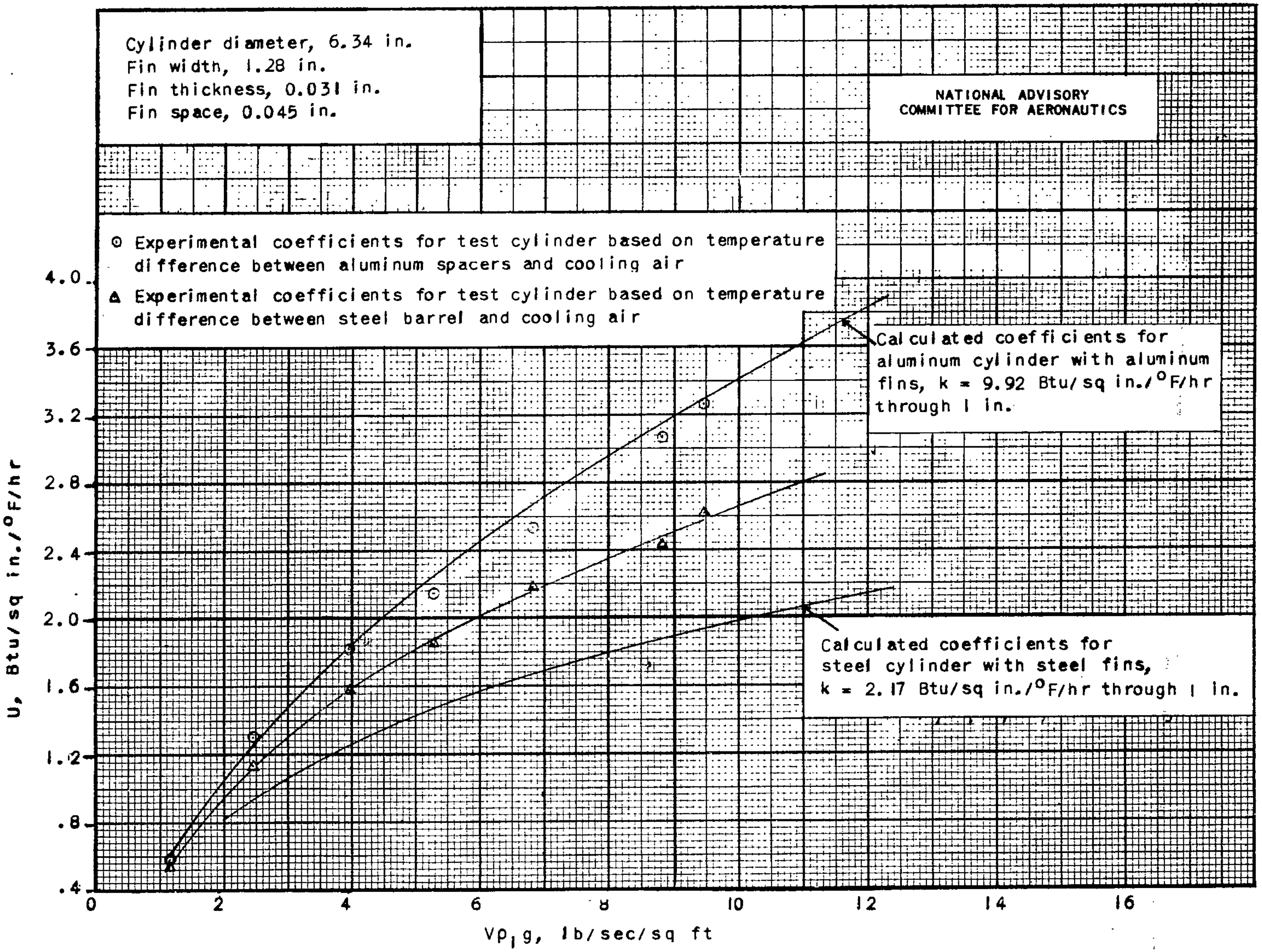

Figure 5. - Comparison of over-all heat-transfer coefficients of test cylinder with calculated coefficients.

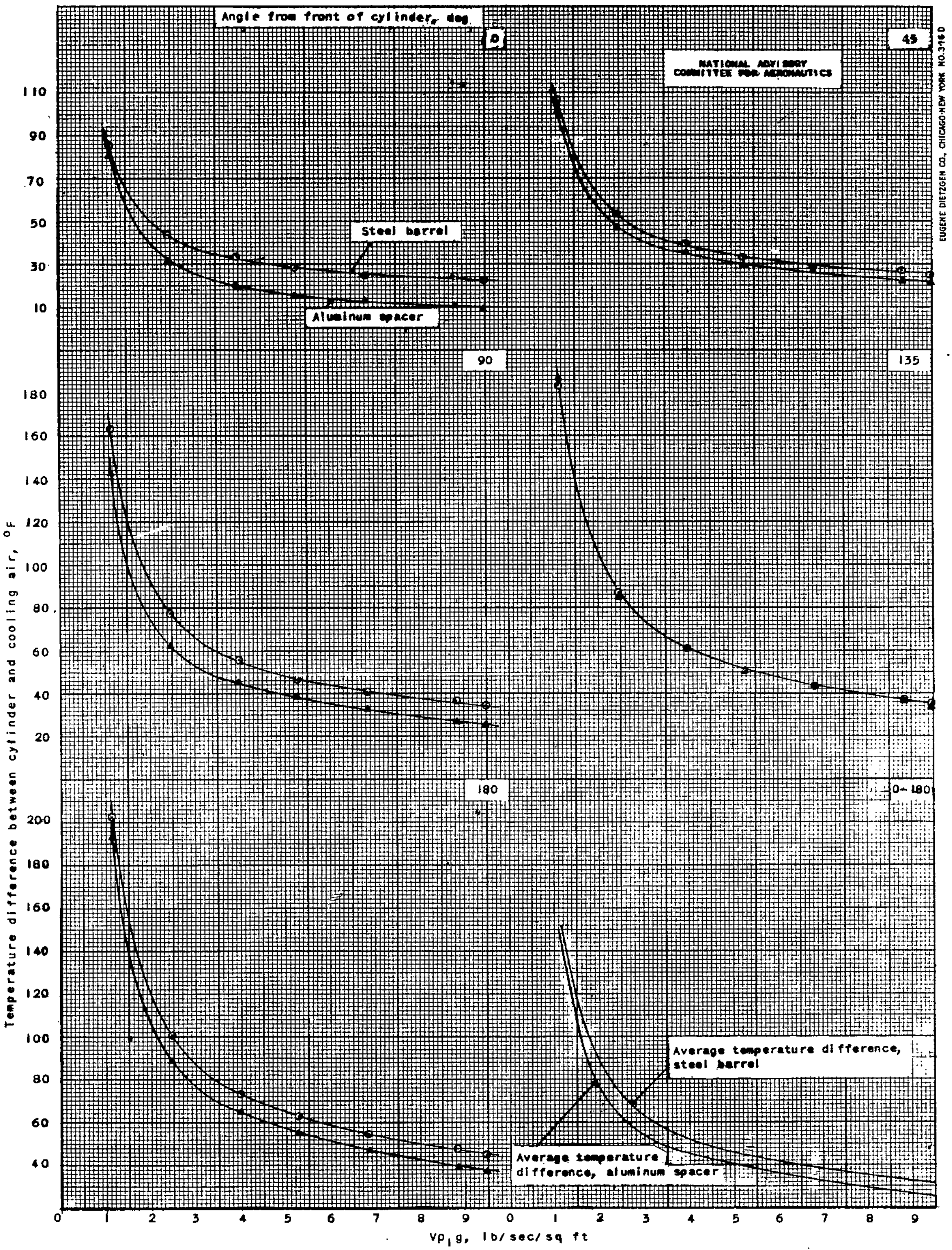

Figure 6. – Comparison of temperatures of steel barrel and aluminum spacers between fins.

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AUTHOR(S)		ATI- 20890
Ellerbrook, H. H.	DIVISION: Power Plants, Reciprocating (6) SECTION: Cooling (1) CROSS REFERENCES: Cylinders, Finned - Cooling (28530)	ORIG. AGENCY NUMBER MR E-194 REVISION

AMER. TITLE: Heat-transfer tests of a steel cylinder barrel with aluminum fins

FORG'N. TITLE:

U

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Aug'39	15		photos, diagr, graphs

ABSTRACT

Heat-transfer tests were conducted on a steel cylinder barrel with aluminum fins to determine the heat-transfer coefficients of the cylinder and the excellence of the bond between the steel barrel and the aluminum fins. A comparison is made of the results with those of steel cylinders with steel fins and aluminum cylinders with aluminum fins. Tests were conducted by varying the speed of the blower, and with an approximately constant heat input to the cylinder of 83 BTU per square inch of wall area per hour. Details of the tests are discussed and the results are presented graphically.

NOTE: Requests for copies of this report must be addressed to: N.A.C.A., Washington, D. C.

AD-B807 219

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23 * Barrels
Heat transfer coefficients
* Fins
Aluminum